

University of Wisconsin - Madison

MADPH-95-874
hep-ph/9503283
March 1995

Radiative b Decays and the Detection of Supersymmetric Dark Matter *

Manuel Drees[†]

Physics Department, University of Wisconsin, Madison, WI 53706, USA

Abstract

The upper bound on the branching ratio for $b \rightarrow s\gamma$ decays implies a stringent lower bound on the mass of the pseudoscalar Higgs boson of the MSSM if sparticles are heavy. This leads to an upper bound on the expected event rate in experiments searching for heavy supersymmetric dark matter. Scenarios with lighter sparticle spectrum and light pseudoscalar Higgs boson are still possible, but only if $\mu < 0$, which again implies a small LSP counting rate.

*To appear in the Proceedings of *Beyond the Standard Model IV*, Lake Tahoe, California, December 1994

[†]Heisenberg Fellow

Recently the CLEO collaboration announced [1] the observation of inclusive $b \rightarrow s\gamma$ decays:

$$Br(b \rightarrow s\gamma) = (2.32 \pm 0.59) \cdot 10^{-4}, \quad (1)$$

where the error is purely statistical. Including systematic uncertainties, this corresponds to the bound

$$Br(b \rightarrow s\gamma) \leq 4.2 \cdot 10^{-4}. \quad (2)$$

Since the systematic uncertainty is large, it is difficult to assign a definite confidence level to this bound; usually it is treated as an “effective” 95% c.l. upper bound.

In the Standard Model (SM), this decay only proceeds via 1-loop diagrams [2], most of which involve heavy particles (W and top). The prediction can therefore change significantly [3] in extensions of the SM that introduce new heavy particles and/or new interactions. In particular, in the minimal supersymmetric standard model (MSSM), three new classes of diagrams contribute [4] to this decay: Diagrams involving a charged Higgs boson and an up-type quark, diagrams with a chargino and an up-type squark, and diagrams with a neutralino or gluino and a down-type squark; in all cases the dominant contribution comes from third generation (s)quarks. The Higgs diagrams always add constructively to the SM contribution, while the contributions from sparticle loops can have either sign.

Diagrams with a gluino or neutralino in the loop are sensitive to the difference in flavor-mixing in the quark and squark sectors, since only a misalignment of these two sectors can generate flavor off-diagonal couplings of the type $\tilde{g}\tilde{q}_i q_j$ ($i \neq j$). If one assumes that squarks are degenerate at some scale, e.g. the Planck or GUT scale, such a misalignment is itself only produced radiatively. In such models one therefore finds [4] gluino contributions to be sub-dominant, while neutralino contributions are negligible. For simplicity I will assume here that the soft SUSY breaking squark masses are degenerate at the weak scale; in this case the gluino and neutralino contributions to $b \rightarrow s\gamma$ decays vanish.

Both the contributions involving a charged Higgs boson and those from squarks and charginos become small if the particles in the loop are heavy; the Higgs contribution decouples less quickly, due to a factor $\log m_{H^\pm}^2/m_t^2$. In the limit of heavy sparticles only the W and Higgs contributions survive; in this situation the bound (2) implies [1] a lower bound on the charged Higgs mass of the order of 300 GeV. In other words, the experimental bound (2) excludes the possibility to combine a heavy sparticle spectrum with a light Higgs sector.

This has immediate bearing [5] on expectations for event rates in dark matter detection experiments. These experiments search for relics from the Big Bang era that might make up the dark matter whose existence has been inferred from the velocity with which objects like gas clouds circulate around the galaxy (so-called rotation curves). In the MSSM the lightest supersymmetric particle (LSP) is stable. In most cases it is the lightest neutralino \tilde{Z}_1 , which for a wide region of parameters has a relic density in the cosmologically interesting range [6]. In the vicinity of the solar system LSPs that have been captured by our galaxy are expected to have a velocity $v \sim 10^{-3}c$; they can therefore only deposit a few keV of energy in a detector, which makes their detection quite difficult.

For most detector materials the LSP-nucleus interaction is dominated by the spin-independent (scalar) contribution to the LSP-nucleon matrix element, since it allows the LSP to interact *coherently* with an entire nucleus. In the limit of a non-relativistic LSP such interactions are [7] due to the t -channel exchange of the neutral scalar Higgs bosons

h^0, H^0 of the MSSM, as well as the exchange of squarks in the s - or u -channel; in most cases the Higgs exchange contributions dominate. Note that quite often the coupling of the lighter scalar Higgs boson h^0 to the LSP is suppressed; the contribution from H^0 exchange can therefore be important even if H^0 is significantly heavier than h^0 . The connection [5] between $b \rightarrow s\gamma$ decays and LSP counting rates becomes obvious once one realizes the close connection between the masses of the charged and heavy neutral Higgs bosons; moreover, the same parameters that determine the masses and couplings of the charginos appearing in SUSY contributions to $b \rightarrow s\gamma$ decays also determine the mass and couplings of the lightest neutralino, i.e. the LSP.

This relation is illustrated in Fig. 1, taken from ref.[5]. Here the solid curves show counting rates in a ^{76}Ge detector [8], while the dashed lines, which refer to the scale to the right, show the predicted $Br(b \rightarrow s\gamma)$. The upper set of curves is for a quite heavy LSP, of about 200 GeV; the lower set is for a much lighter particle spectrum, with $m_{\text{LSP}} \simeq 50$ GeV.

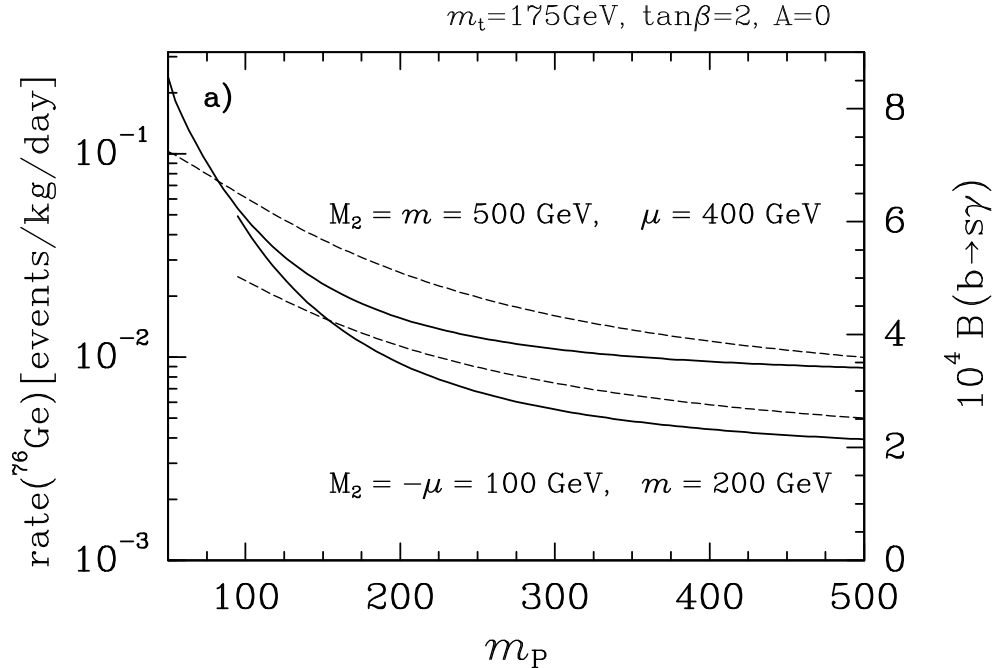


Fig. 1: Prediction of the dependence of the LSP counting rate in a ^{76}Ge detector (solid lines) and $Br(b \rightarrow s\gamma)$ (dashed lines) on the mass m_P of the pseudoscalar Higgs boson. Results are presented for $m_t = 175$ GeV and two different particle spectra, as indicated. Here, M_2 is the mass of the $SU(2)$ gaugino, μ the higgsino mass parameter, and m the soft breaking squark mass.

We observe that both the LSP counting rate and the branching ratio for radiative b decays decrease with increasing mass m_P of the pseudoscalar Higgs boson. The branching ratio decreases since increasing m_P also increases the mass of the charged Higgs boson, and the counting rate decreases since increasing m_P raises the mass of the heavy neutral Higgs scalar. Notice that the lower dashed curve falls below the SM expectation of $2.85 \cdot 10^{-4}$ for the branching ratio if $m_P > 350$ GeV; the reason is that for the given choice of parameters

(negative μ , vanishing soft breaking parameter A) the chargino–squark diagrams have the opposite sign as the SM and charged Higgs contributions. For the heavy LSP case the contribution from SUSY loops is almost negligible; the fact that the upper dashed curve is well above the SM expectation even for $m_P = 500$ GeV illustrates the rather slow decoupling of the charged Higgs contributions. The bound (2) implies $m_P \geq 320$ (150) GeV for the heavy (light) LSP scenario of Fig. 1, which leads to an upper bound on the counting rate of 0.012 (0.015) events/(kg·day).

Fig. 2 shows contours of constant counting rate and constant $Br(b \rightarrow s\gamma)$ in the (M_2, μ) plane, for both signs of μ . In both cases the region underneath the solid line is excluded by SUSY searches at colliders (region of small M_2 or small $|\mu|$), or by the requirement that the lightest (stop) squark be heavier than the lightest neutralino (small M_2 , large $|\mu|$); note that the soft breaking squark mass $m = 2m_{\text{LSP}}$ here. Moreover, in the areas enclosed by the dotted lines (sizable M_2 and $|\mu| \leq M_2/2$) the LSP relic density is too small to be of cosmological interest; here the LSP cannot form the dark matter in galactic haloes. Notice that requiring a sufficiently large LSP density already excludes a substantial part of the plane where a counting rate exceeding 0.1 events/(kg·day) could be expected if the local LSP density were fixed.*

Imposing the bound (2) further limits the available region of the (M_2, μ) plane. For $\mu > 0$, only the small area around $M_2 = 100$ GeV, $\mu = 450$ GeV below the long dashed curve survives; in particular, the entire region where the counting rate exceeds 0.1 events/(kg·day) is now excluded. For negative μ the much larger region below and to the right of the long dashed curve is still viable; however, as we already saw in Fig. 1, the counting rate is always quite small if $\mu < 0$.

Unfortunately the prediction for $Br(b \rightarrow s\gamma)$ is still quite uncertain, mostly due to unknown higher–order QCD corrections; experimental errors on CKM matrix elements and the like also play a role. In ref.[2] this uncertainty has been estimated to be about $\pm 25\%$ in the SM. The same sources of uncertainty also exist in the MSSM. The long dashed curve in Fig. 2 labelled “low” ($\mu > 0$ only) has been computed by subtracting one theoretical “standard deviation” from the best estimate, using the formalism of ref.[2]. Only the region below this curve (at $M_2 \simeq 120$ GeV, $\mu \simeq 200$ GeV) is in conflict with the bound (2) if this lower theoretical estimate is used. However, when combined with the requirement of a sufficiently large LSP relic density this still excludes almost the entire region where the counting rate exceeds 1 event/(kg·day). If this lower theoretical estimate for $Br(b \rightarrow s\gamma)$ is used the entire half plane with $\mu < 0$ remains viable. It should be mentioned, however, that the bound (2) is based on a rather conservative treatment of the systematic uncertainties; in particular, statistical and systematic errors have been added linearly. In my opinion combinations of parameters which give a central estimate for $Br(b \rightarrow s\gamma)$ that violates the bound (2) while the lower theoretical estimate does not, are therefore already strongly disfavoured, although

*In fact, the region of too small relic density is slightly bigger than shown in Fig. 2; narrow strips of low relic density, where some s –channel LSP annihilation diagram becomes resonant, have been omitted in these figures in the interest of greater clarity.

it might be somewhat premature to exclude them altogether.

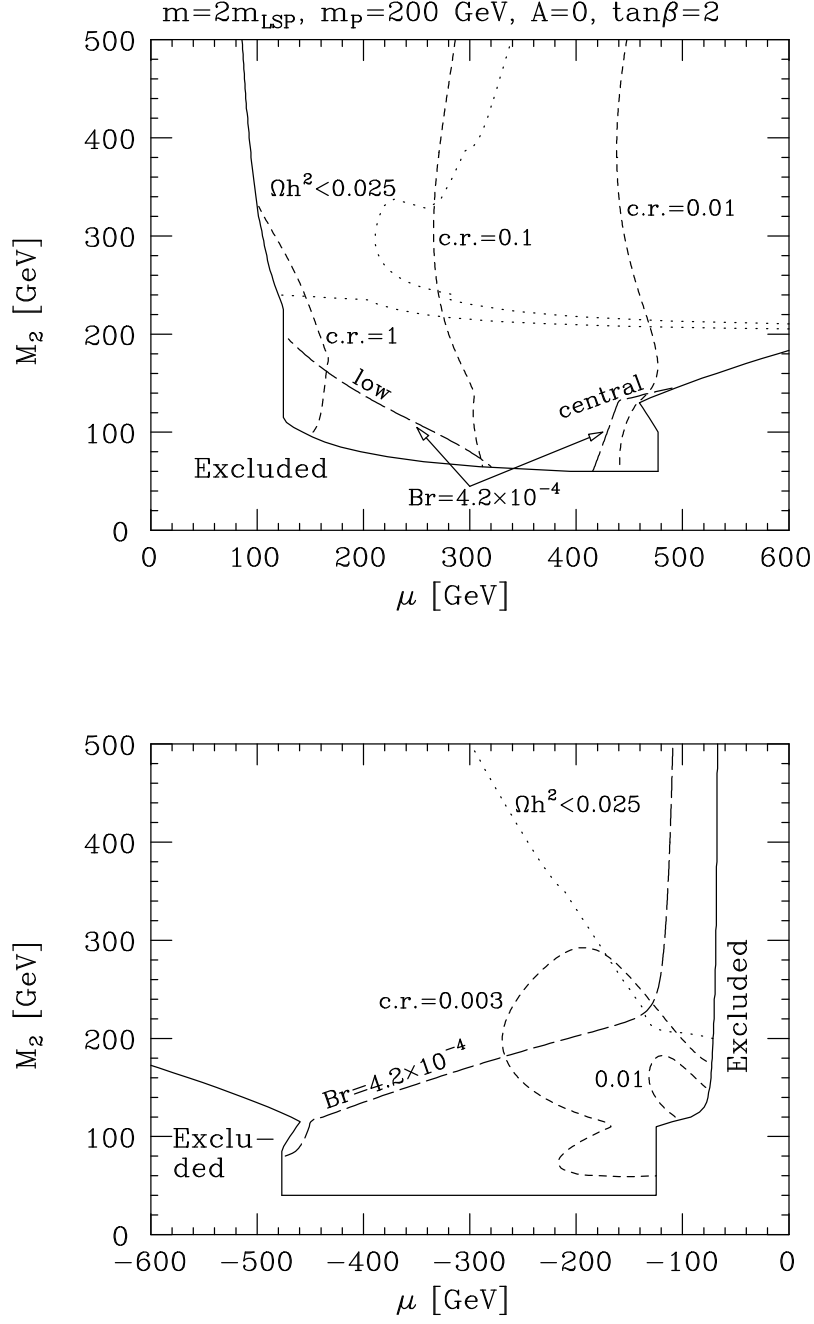


Fig. 2: Contours of constant LSP counting rate in a ^{76}Ge detector [short dashed lines, in events/(kg·day)] and of constant $\text{Br}(b \rightarrow s\gamma) = 4.2 \cdot 10^{-4}$ (long dashed lines) in the (M_2, μ) plane; the two long dashed curves for $\mu > 0$ correspond to different theoretical estimates of $\text{Br}(b \rightarrow s\gamma)$, as discussed in the text. The regions enclosed by the dotted lines have too small a relic density for the LSP to be a good dark matter candidate.

Finally, it should be mentioned that in “minimal supergravity” models with radiative gauge symmetry breaking a heavy sparticle spectrum more or less automatically implies heavy pseudoscalar and charged Higgs bosons; the impact of the bound (2) on the expected LSP detection rate is therefore weaker in such models [9]. Notice that these models generally predict a rather low counting rate anyway [7, 9]. However, such models entail several assumptions about physics at scales well above the weak scale. It is therefore important to emphasize that now a purely experimental bound forces us to expect rather low rates for dark matter search experiments if dark matter is indeed made from superparticles.

Acknowledgements

I wish to thank my collaborators Francesca Borzumati and Mihoko Nojiri; without them, ref.[5] would not have been written and I would have missed the opportunity to have a truly cold lunch. This work was supported in part by the U.S. Department of Energy under Grant No. DE-FG02-95ER40896, by the Wisconsin Research Committee with funds granted by the Wisconsin Alumni Research Foundation, as well as by a grant from the Deutsche Forschungsgemeinschaft under the Heisenberg program.

References

- [1] CLEO Collab., M.S. Alam et al., preprint CLNS-94-134.
- [2] A.J. Buras, M. Misiak, M. Münz and S. Pokorski, Nucl. Phys. **B424**, 374 (1994).
- [3] See e.g. J.L. Hewett, SLAC-PUB-6521, hep-ph 9406302, and references therein.
- [4] S. Bertolini, F.M. Borzumati, A. Masiero and G. Ridolfi, Nucl. Phys. **B353**, 591 (1991).
- [5] F.M. Borzumati, M. Drees and M.M. Nojiri, Phys. Rev. **D51**, 341 (1995).
- [6] M. Drees and M.M. Nojiri, Phys. Rev. **D47**, 376 (1993), and references therein.
- [7] M. Drees and M.M. Nojiri, Phys. Rev. **D48**, 3483 (1993), and references therein.
- [8] D.O. Caldwell et al., Phys. Rev. Lett. **61**, 510 (1988), and Phys. Rev. Lett. **65**, 305 (1990).
- [9] P. Nath and R. Arnowitt, Phys. Lett. **B336**, 395 (1994), and preprint CERN-TH-7363-94, hep-ph 9409301.